



Occurrence of chilling injury in fresh-cut ‘Kent’ mangoes

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ABSTRACT

For best visual quality retention of fresh-cut fruits, the preferred storage temperature is never higher than 5 °C, which is considered a chilling temperature for chilling sensitive tropical fruit like mango. Changes in visual and compositional attributes, aroma volatile production, respiration rate, and electrolyte leakage were evaluated in whole and fresh-cut partially ripe ‘Kent’ mangoes stored for 10 d at chilling (5 °C) and non-chilling (12 °C) temperatures in order to determine if fresh-cut mangoes are subject to chilling injury at their typical handling temperature. The experiment was conducted twice during two Florida mango seasons, with fruit from two different sources. Results from the two harvests were significantly different and therefore were analyzed separately. Visual quality degradation was faster at 12 °C than at 5 °C, and limited the shelf-life of the fresh-cut mangoes to 3–4 d at 12 °C versus 5–6 d at 5 °C. Soluble solids content did not differ among whole fruit or fresh-cut slices stored at either chilling or non-chilling temperatures, but respiration rate, pH, and total ascorbic acid were all lower and titratable acidity was higher in both the fresh-cut slices and whole fruit stored at 5 °C compared with storage at 12 °C. Subjective evaluation indicated that aroma intensity declined more during storage of fresh-cut slices at 5 °C than at 12 °C, and the aroma volatiles acetaldehyde, ethyl acetate, and ethyl butyrate were found to be significantly reduced in the slices stored at 5 °C, but only in the second harvest; production of alcohols (methanol and ethanol) was also lower in samples stored at 5 °C. Although electrolyte leakage was higher in fresh-cut slices than in whole fruit, no conclusion could be made regarding the effect of storage temperature. It is unclear whether the storage duration at 5 °C was sufficiently long to cause chilling injury in fresh-cut mango slices since no visual symptoms developed in whole fruit. However, lower ascorbic acid content, higher titratable acidity, reduction of volatiles, and increased softening of whole fruit at 5 °C versus 12 °C, which are all indicative of CI, suggest that the fresh-cut mango slices did experience chilling stress.

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1. Introduction

To preserve the quality and safety of fresh-cut fruits and vegetables and to extend the shelf-life, good temperature management is of prime importance. Due to their highly perishable nature, fresh-cut fruits are preferably stored at a temperature that may cause a slight amount of chilling injury (CI) over a temperature that is conducive to rapid natural deterioration (Watada and Qi, 1999). However, it is possible that low temperature storage of fresh-cut tropical fruit, like mangoes (*Mangifera indica* L.), may jeopardize their overall sensory quality by inducing CI.

Poor flavor retention in fresh-cut products, especially fruit, is a widely recognized problem (Beaulieu and Gorny, 2004) and may

be a symptom of CI related to inhibition of aroma volatile production. Moreover, some indications that fresh-cut products are subjected to CI have been noted despite little visual manifestations. For example, elevated respiration rates in fresh-cuts compared to the corresponding whole fruit may in some cases and to some extent, be an indicator of CI (Brecht et al., 2004). Juice leakage or tissue translucency due to membrane damage and solute leakage that occurs in fresh-cut tomatoes and melons is a critical problem in commercial fresh-cut products. It has been suggested that these symptoms may be manifestations of CI in fresh-cut tropical and subtropical fruit (Hong and Gross, 2000; Hodges and Toivonen, 2008). Besides, it may be possible to extrapolate the symptoms of CI occurring in whole fruit to their fresh-cut products, such as softening or other textural changes, increased rates of electrolyte leakage (EL), skin/peel darkening, loss of pigments, and increase in CO₂ production (Hodges and Toivonen, 2008).

Although CI of whole mango is well documented (Abou Aziz et al., 1976a,b; Thomas and Oke, 1983; Chaplin et al., 1991; Lizada, 1991; Nair et al., 2004), very few studies have addressed the effect

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of temperature on the incidence and development of CI symptoms on fresh-cut mango (Beaulieu and Lea, 2003; Allong et al., 2000; Sothornvit and Rodsamran, 2008). In fact, most studies have indirectly reported the effect of temperature and focused on only a few quality attributes, often combined with different treatments that are known to alleviate CI, at least in whole fruit, such as coatings or modified atmosphere packaging (González-Aguilar et al., 2001; Tasneem, 2004; Pesis et al., 1997; Tefera et al., 2007). Therefore, a general conclusion regarding the occurrence of CI symptoms in fresh-cut mango remains unsettled. There may be sufficient expectation that the flavor of fresh-cut mango could be improved by avoiding chilling temperatures to justify efforts to develop supplementary treatments and procedures that allow this product to be handled at higher temperatures than those currently being used.

This study was conducted to evaluate the occurrence of CI in fresh-cut 'Kent' mango, using fresh-cut mango slices and whole mango fruit controls stored at chilling versus non-chilling storage temperatures.

2. Materials and methods

2.1. Plant material

This study was conducted twice during two Florida harvest seasons. Mangoes (cv. Kent) were obtained from a commercial operation in Homestead, FL [first harvest (H1), July 2006] and from the University of Florida Tropical Research and Education Center in Homestead, FL [second harvest (H2), July 2007]. Fruit were removed from the field with minimal delay after harvest and transported to the postharvest laboratory in Gainesville, FL, within approximately 6 h. Mangoes were selected based on uniformity of size, color, and freedom from defects.

All fruit received a quarantine hot water treatment following the USDA treatment schedule T102-a (USDA-APHIS, 2005). Mangoes were immersed in water at 46 °C for 90 or 75 min for fruit with weights greater than 500 g or less than 500 g, respectively. Following the HW treatment, fruit were left at room temperature (24 °C) for about 90 min to cool down and dry before being transferred to a 20 °C temperature controlled room for a 24-h ethylene treatment (100 $\mu\text{L L}^{-1}$). Following ethylene treatment, the fruit were allowed to ripen at 20 °C until the desired ripeness stage was attained as determined by flesh firmness that yielded to gentle hand pressure (3–4 d after ethylene treatment), which resulted in slices with average initial firmness of $33.0 \pm 4.5\text{N}$ (H1) or $29.2 \pm 3.8\text{N}$ (H2). The partially ripe mangoes were then held overnight in refrigerated and sanitized rooms at either 5 or 12 °C before being processed into fresh-cut slices.

Half of the fruit at each temperature were processed into fresh-cut slices while the other half were left whole (control). Before being peeled, mangoes were dipped for 3 min in a 1.34 mM sodium hypochlorite solution at 5 °C, adjusted to pH 7 with 2N citric acid solution. After peeling, mangoes were submerged for 3 min in a fresh 1.34 mM chlorinated water bath at 5 °C before being drained and cut into slices. Each peeled mango was halved and cut into eight longitudinal slices. All mango slices were pooled and randomized before being distributed into polyethylene terephthalate (PETE) containers with leak-free snap-on covers that had a 1.5-cm diameter hole filled with a cotton ball to assure good air circulation and avoid microbial contamination. Whole fruit controls and a total of eight mixed slices per container were stored at 5 or 12 °C for 10 d. Four whole fruit and four containers of fresh-cut slices per treatment were used for the analysis at each sampling time. Prior to analysis, the whole fruit were also processed into fresh-cut slices as described above.

2.2. Subjective quality evaluation

The visual quality of each sample of fresh-cut mango slices was assessed on days 0, 2, 5, 7 and 10 at 5 or 12 °C using 9-point visual rating scales for overall color, edge tissue damage, spoilage, aroma, and desiccation with higher numbers corresponding to better quality as previously designed and used by Beaulieu and Lea (2003). All visual evaluations were performed by the same trained person.

2.3. Respiration rate measurements

Four containers of fresh-cut and four whole fruit stored at 5 or 12 °C were individually sealed in 2 L plastic containers for 1–2 h prior to gas sampling. Samples (0.5 mL) of the headspace were withdrawn and CO₂ levels were analyzed using a Gow-Mac (Series 580, Bethlehem, PA, USA) gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a 1.2 m \times 3.18 mm Porapak Q [particle size 149–177 μm (80/100 mesh)] column. The carrier gas (helium) flow rate was 0.5 mL s⁻¹. The detector and injector were operated under ambient conditions (23 °C) and the oven was at 40 °C. Respiration rate as CO₂ production is expressed in $\mu\text{g kg}^{-1} \text{s}^{-1}$. CO₂ was quantified using a standard gas mixture containing 1.02% CO₂. Respiration rate was measured on the same samples from days 0, 2, 4, and 8 for H1 and from days 0, 3, 4, 6 and 8 for H2.

2.4. Electrolyte leakage

Twelve mesocarp tissue plugs (5 mm diameter \times 10 mm length) per eight-slice sample were excised from fresh-cut slices using a No. 5 brass cork borer. The mesocarp plugs were cleaned of damaged cells by rinsing gently with deionized water before being incubated for 3 h at room temperature (24 °C) in 30 mL solution of 0.7 mol L⁻¹ isotonic mannitol in water. The electrical conductivity of the solution was measured using an YSI Conductivity Instrument (YSI Inc., Yellow Springs, OH). Total electrolytes were determined after freezing at -20 °C, thawing, and re-warming to room temperature. Three measurements per sample were taken. Electrolyte leakage was expressed as a percent of the conductivity of total tissue electrolytes.

2.5. Firmness evaluation

In H2, firmness was measured using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat plate probe (5-cm diameter) and equipped with a 50-kg load cell. The measurements were made on four fresh-cut slices per sample, positioning the probe over the largest flat side of each slice, after establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 0.8 mm s⁻¹. The force was recorded at 2.5 mm deformation. The results were expressed in Newtons.

2.6. Flesh color measurements

The flesh color (L^* , a^* , b^*) of mango fruit from H2 was measured on the cut surface of the slices with a reflectance colorimeter (Minolta CR 200b, Minolta Corp., Ramsey, NJ). There were a total of 10 measurements per treatment. Numerical values of a^* and b^* were converted into hue angle ($H^\circ = \tan^{-1} b^*/a^*$) (Francis, 1980).

2.7. Compositional analysis

Samples destined for compositional analysis were homogenized and kept frozen at -20 °C in air-tight plastic freezer bags until used.

Table 1
ANOVA table for visual quality and aroma of fresh-cut 'Kent' mango slices.

Source of variations	d.f.	F-value				
		Overall color	Edge or tissue damage	Aroma	Spoilage	Desiccation
Harvest 1						
Storage duration	4	150.63***	67.34***	88.94***	33.29***	175.05***
Storage temperature	1	13.98**	14.12**	12.93**	3.48**	18.57**
Harvest 2						
Storage duration	4	379.95***	1104.80***	313.05***	18.08***	292.50***
Storage temperature	1	0.09 ns	92.00***	21.84***	0.01 ns	21.82***

ns = non-significant.

** Significant at $P < 0.01$.

*** Significant at $P < 0.001$.

2.7.1. pH, titratable acidity and soluble solids content

Each individual sample replicate was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at $17,600 \times g$ for 25 min. The resulting clear juice was decanted from the centrifuge tubes and the pH and titratable acidity were determined using an automatic titrimeter (Metrohm Ion analysis Ltd., model 719 S Titrimo, Switzerland). Aliquots (6.00 g) of mango juice were diluted with 50 mL distilled water and the titratable acidity determined by titration with 0.1N sodium hydroxide (NaOH) to an end point of pH 8.2. Titratable acidity was expressed as percent citric acid. The soluble solids content (SSC) of the clear juice samples was determined with an Abbe refractometer (Cambridge Instruments, Inc., Buffalo, NY) and expressed as percent juice fresh weight.

2.7.2. Total ascorbic acid

For each sample, 2.5 g of homogenized mango tissue were mixed with 50 mL of a mixture of 6% metaphosphoric acid and 2N acetic acid. Samples were kept frozen in glass containers at -20°C until analysis. After thawing, the fruit–acid mixture was centrifuged for 20 min at $17,600 \times g$. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total ascorbic acid was calculated from absorbance measured at 540 nm using a standard curve prepared from a serial dilution of an ascorbic acid standard solution (Sigma–Aldrich Co., St. Louis, MO). Concentration of ascorbic acid was expressed in terms of fresh weight.

2.7.3. Volatile analysis

Samples for volatile analysis were prepared by combining 1.5 g of mango homogenate with 1.5 g of distilled water in a 10-mL gas chromatography vial, crimp-capped and flash frozen in liquid nitrogen. The samples were stored at -20°C before analysis. The headspace analysis was conducted using an Agilent 6890N GC equipped with a flame ionization detector (FID) and a $0.53 \text{ mm} \times 30 \text{ m}$, $1.0 \mu\text{m}$ film thickness, polar Stabilwax column. Volatiles were quantified using calibration curves obtained from deodorized mango homogenate, in which volatiles are first removed by rotary evaporation (Malundo et al., 1997; Plotto et al., 2006), and then spiked with five levels of authentic standards (Sigma–Aldrich Co., St. Louis, MO). Sixteen aroma volatiles were measured and quantified: acetaldehyde, hexanal, acetone, methanol, ethanol, α -pinene, β -pinene, limonene, p -cymene, α -copaene, 3-carene, myrcene, terpinolene, caryophyllene, ethyl acetate, and ethyl butyrate.

2.8. Statistical analysis

A completely randomized design was used for this study with the evaluation or analysis of composite samples of eight slices from four replicate containers per treatment and sampling time, except that 10 color measurements were made on 10 slices taken from four

containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. Data were analyzed using the General Linear Model procedure of SAS (SAS Institute, version 9.1, Cary, NC), to identify significant main effects due to storage duration, fresh-cut versus whole, and storage temperature. Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The harvest seasons, H1 and H2, showed significantly different effects for all treatments evaluated, and were therefore analyzed separately. This difference could be explained by different climatic conditions and/or the location where the mangoes were grown.

3. Results and discussion

3.1. Subjective quality

Storage duration and temperature had a significant effect on the visual quality of fresh-cut 'Kent' mango slices (Table 1). The visual quality (edge and tissue damage, overall color, spoilage, and desiccation) and aroma of slices from both harvests and storage temperatures decreased consistently during storage but the changes were significantly faster at 12°C than at 5°C (Fig. 1).

In this study, the marketability limit for the fresh-cut mango slices was determined when one or more attributes reached a subjective score (limit) of 5; at that point the product was considered to be unsalable at the retail level, but could still be suitable for consumption with partial trimming. For H1, the fresh-cut slices stored at 12°C reached the marketability limit (rating of 5) after 3–4 d of storage, compared to 5 d at 5°C (Fig. 1). The shelf-life of fresh-cut mango slices stored at 5°C was limited by edge tissue damage, characterized by edges that were slightly soggy or water-soaked with darker color, veins markedly brown, and a gooey appearance from tissue breakdown, while the slices stored at 12°C rapidly became water-soaked, with obvious edge damage, like compression bruising, with a gooey appearance and a strong fermented off-odor.

For H2, the shelf-life of fresh-cut slices stored at 5°C was limited to 5 d due to desiccation, characterized by a progressive drying of the slice edges with little to no surface gleam, and slightly dehydrated surfaces (Fig. 1). At 12°C , the slices became unmarketable after about 3–4 d due to progressive drying, followed by off-odor, edges slightly soggy or water-soaked with darker color, and slight softening of the tissues.

Even though the variability in the shelf-life of fresh-cut mango depends mostly on the cultivar and the ripeness stage of the fruit at harvest (Allong et al., 2001), in this study slices stored at 5 or 12°C had similar shelf-life compared with values previously reported in the literature. For example, Rattanapanone et al. (2001) reported that the marketable period of fresh-cut 'Tommy Atkins' and 'Kent' mango cubes was 3–5 d at 10°C and 5–8 d at 5°C , and shelf-life was limited by watery condition, discoloration, and loss of fresh

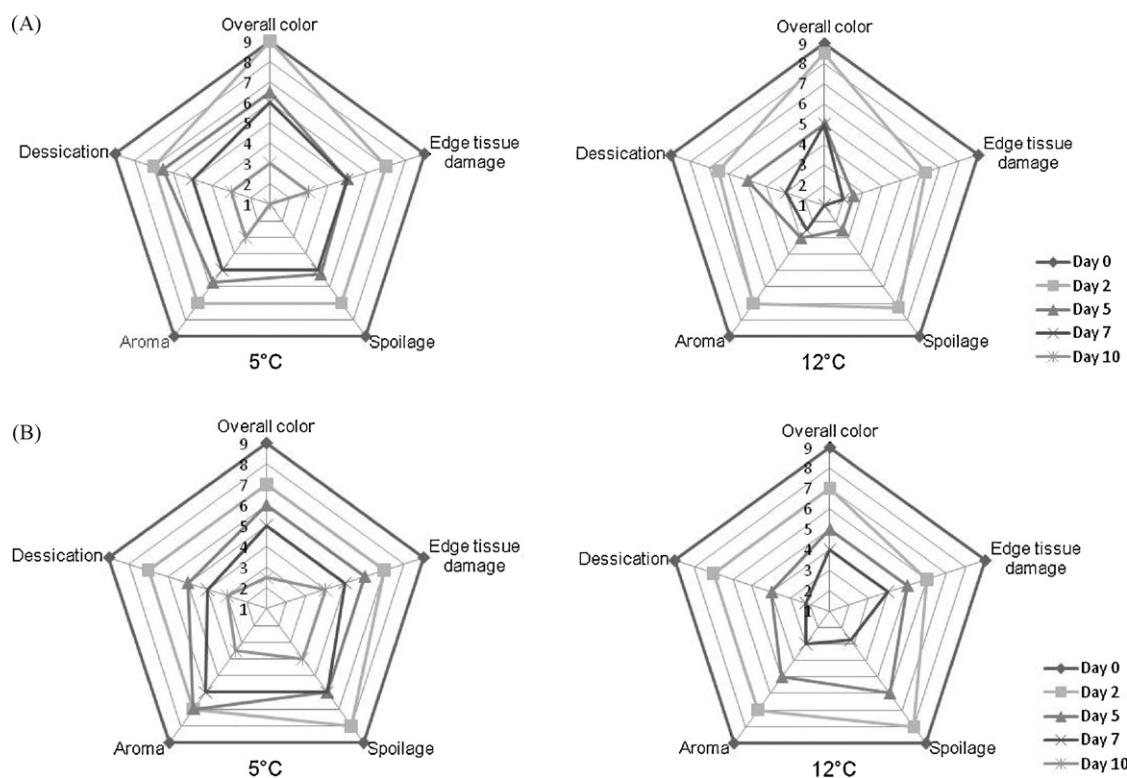


Fig. 1. Subjective visual evaluation of fresh-cut 'Kent' mango slices during storage at 5 or 12 °C: (A) Harvest 1 and (B) Harvest 2. Generally 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/or loss; 1 = poor, inedible. Five is the minimum subjective score (limit) for marketing any product.

appearance of the mango cubes. The shelf-life of 'Nam Dokmai' mango cubes was only 2 d at 5 °C and 1 d at 13 °C, and was limited by browning and water-soaked appearance on the cut surfaces (Poubol and Izumi, 2005a,b). Beaulieu and Lea (2003) reported that shelf-life of fresh-cut mango cubes from "soft-ripe" mangoes was limited to 7 d when stored at 4 °C with the most critical factor being edge or tissue damage, resulting in mushy tissue and poor texture, followed by aroma loss and general discoloration.

Compared with fresh-cut slices stored at 12 °C, slices stored at 5 °C did not show any visible signs of CI. However, the natural visual quality loss of the fresh-cut slices was faster at higher temperature. Moreover, even though the grading system used for evaluating fresh-cut mango aroma was designed to detect off-odors in the samples, little aroma was perceived in the slices stored at 5 °C compared with freshly prepared slices from stored whole fruit (data not shown). Loss in aroma was previously reported in fresh-cut fruits (Beaulieu and Gorny, 2004; Forney, 2007) and has been identified as a symptom of CI in whole mango fruit (Nair et al., 2003, 2004). On the other hand, no external CI symptoms developed on whole mangoes stored at 5 °C during the same storage period as fresh-cut mango slices (data not shown). Even though the whole fruit were not transferred to room temperature to allow the CI symptoms to develop, it is plausible that the fruit may not have suffered from CI since they were partially ripe when exposed for a short period to 5 °C. Susceptibility of mango fruit to CI declines as the fruit mature and ripen. For example, immature 'Tommy Atkins' mangoes stored at 5 °C for 18 d exhibited higher incidence of CI upon warming to 20 °C than half-mature fruit, which showed a trace of CI, and mature fruit, which showed no trace of CI (Mohammed and Brecht, 2002).

3.2. Respiration rate measurements

The overall respiration rate (RR) of fresh-cut slices was significantly higher than that of whole fruit for both harvests (Table 2

and Fig. 2). Storage duration and temperature did not significantly affect the RR of whole or fresh-cut mango in H1 (Table 1), but had a significant effect on the RR of fruit from H2 (Table 2) with fruit stored at 12 °C exhibiting higher RR than fruit stored at 5 °C (Fig. 2).

In general, the RR of the fresh-cut slices stored at 5 °C decreased from days 0 to 2, to rates that were similar to those of whole fruit, and remained comparable for the rest of the marketable period, except for a burst of respiration measured on day 4 of H2, the cause of which is unknown. At 12 °C, however, the RR of the slices decreased during storage to reach rates similar to whole fruit only at day 8, which was past the marketability limit.

The RR of fresh-cut mango slices measured in this study was in accordance with the data previously reported. For example, Allong et al. (2001) showed high RR for 'Julie' and 'Graham' mangoes measured immediately after slicing, with RR decreasing significantly within the first 12 h of storage at 5 or 10 °C. Slices held at 10 °C produced substantial amounts of CO₂ but storage at 5 °C greatly reduced CO₂ production rates at all stages of ripeness (Allong et al., 2001).

3.3. Electrolyte leakage

For both harvests, higher electrolyte leakage (EL) was measured from fresh-cut slices that were stored for a few days before analysis compared to the whole fruit controls that were cut on the day of analysis (Table 2). This is to be expected since EL is an indicator of loss of cell membrane integrity attributed to ripening, or any damage that can arise from stress or mechanical injury (Nyanjage et al., 1999).

For H1, storage at 5 °C induced higher EL from fresh-cut slices than storage at 12 °C, while the levels of EL for whole fruit stored at 5 or 12 °C were similar, and tended to decrease during storage

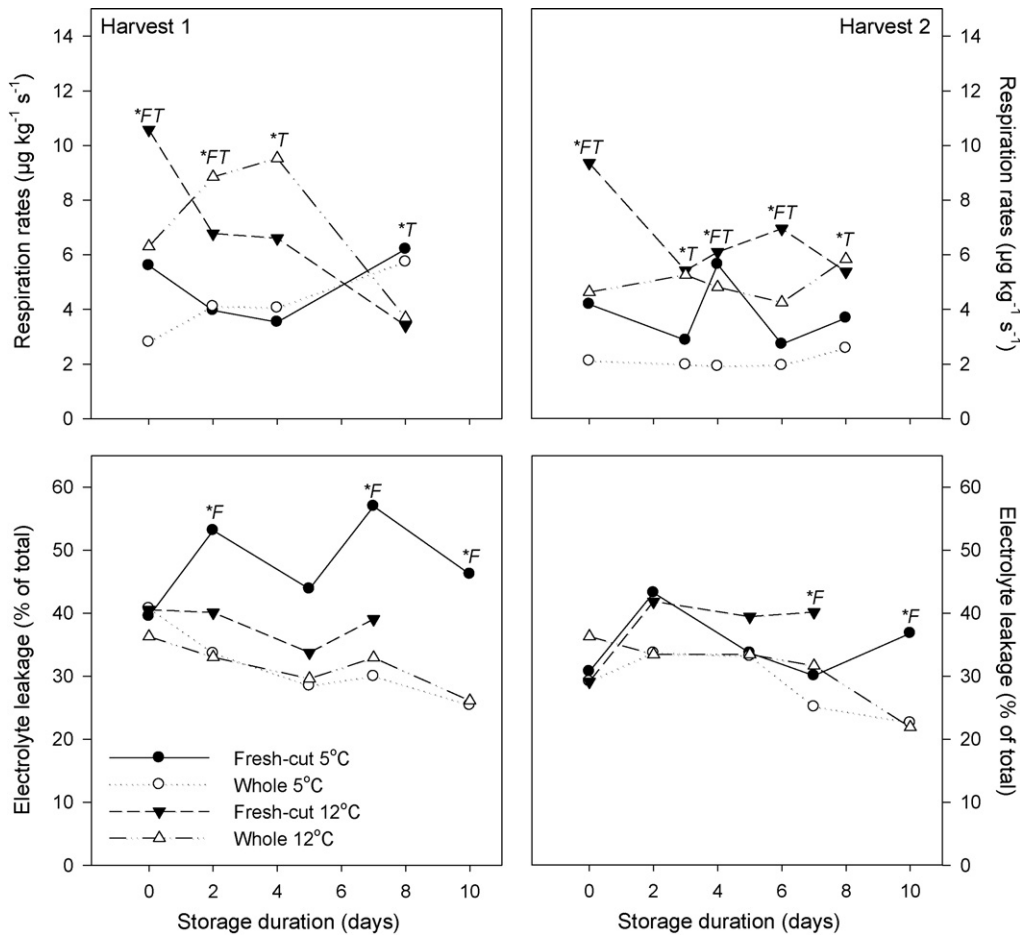


Fig. 2. Changes in respiration rate and electrolyte leakage during storage of fresh-cut 'Kent' mango slices and whole mangoes stored at 5 and 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 and 12 °C), or both, respectively, using the LSD test.

(Fig. 2). The high EL of fresh-cut tissue at 5 °C compared with slices stored at 12 °C may be a sign of CI related to loss of integrity of the fruit tissue (Vicente et al., 2006), while the decrease of EL in whole fruit could be attributable to further ripening that may have led to higher osmotic potential and thereby reduced electrolyte leakage (Nyanjage et al., 1999).

On the other hand, for H2, storage temperature did not have a significant effect on the EL level during storage, while storage duration and the type of sample significantly affected the EL measured (Table 2). In fact, the EL of fresh-cut slices was significantly higher than that of whole fruit after the marketable period had passed (Fig. 2). The EL of whole fruit tended to decrease slightly during storage, as also observed in H1, while the EL measured in fresh-cut slices from both storage temperatures showed a similar increase from days 0 to 2, and a decrease during the rest of the storage period.

3.4. Firmness

Storage duration and fresh-cut processing had significant effect on the firmness of the fruit whereas storage temperature had no significant effect on fruit firmness (Table 2). For both harvests, slice firmness decreased during storage regardless of the temperature. However, greater softening occurred in the fresh-cut slices than in the whole fruit (Fig. 3). In this study, the fresh-cut slices were prepared a few hours earlier than the initial whole fruit samples were cut, and the firmness of all of the sample replicates was measured at the same time, which may have contributed to the ini-

tial lower firmness (day 0) of fresh-cut slices compared to whole fruit.

Fresh-cut mango slices stored at 5 °C showed a slight increase in firmness during storage, while a significant loss of firmness was measured for the slices stored at 12 °C. More interestingly, firmness of whole fruit stored at 5 °C decreased by approximately 31.0% during storage while no change in firmness occurred in the whole fruit stored at 12 °C. This difference may be attributable to CI caused by exposure of the fruit to low temperature. It is recognized that the primary response to chilling temperatures involves a decrease in fluidity of the micro-domains of cell membranes, and damage to critical membrane proteins leading to increased membrane rigidity, resulting in softening of the tissue (Wang, 1982; Kays, 1991). The decrease in firmness in whole mango fruit stored at 5 °C suggests that CI may have occurred during storage in both whole fruit and fresh-cut mango slices.

3.5. Flesh color

Storage duration, storage temperature and fruit type (whole or fresh-cut) had a significant effect on the lightness (L^* value) of the slices (Table 2). The lightness of the flesh from whole fruit tended to increase during storage (Fig. 3), while the flesh lightness of the fresh-cut slices decreased during storage, indicating darkening of the surface color. The increase in lightness of the whole fruit may be attributable to a loss of green color that occurred prior to a rise in yellow-orange color as indicated by an increase in a^* value, which followed a similar pattern to the L^* value during storage (data not

Table 2
ANOVA table for respiration rates, electrolyte leakage, firmness, hue angle, lightness, and composition of fresh-cut ‘Kent’ mango slices and whole mangoes.

Source of variation	d.f.	F-value										
		RR ^a (μg kg ⁻¹ s ⁻¹)	EL ^b (% of total)	Firmness (N)	Hue angle (°h)	Lightness (L*)	pH	TA (%)	SSC (%)	AA (g kg ⁻¹)	Total non-alcohol volatiles (μL L ⁻¹)	Total alcohol volatiles (μL L ⁻¹)
Harvest 1												
Storage duration	4	1.26 ns	2.39ns	–	–	–	14.66***	7.11***	0.95 ns	1.16 ns	4.23**	2.21**
Fresh-cut/whole fruit (F–W)	1	15.62**	30.02***	–	–	–	0.28 ns	0.52 ns	9.46**	2.91 ns	2.96 ns	0.77 ns
Storage temperature (T)	1	0.01 ns	7.12**	–	–	–	62.97***	20.58***	4.82*	10.88**	0.02 ns	2.69 ns
(T) × (F–W)	1	1.10 ns	6.97*	–	–	–	0.92 ns	2.01 ns	0.60 ns	1.76 ns	2.61 ns	0.008 ns
Harvest 2												
Storage duration	4	3.22*	5.51**	33.01***	4.79**	3.87**	57.80***	66.22***	0.45 ns	13.76**	2.81 ns	1.62 ns
Fresh-cut/whole fruit (F–W)	1	138.69***	20.01***	78.17***	1.46 ns	118.77***	7.69**	0.24 ns	26.92***	36.13***	2.77 ns	17.31***
Storage temperature (T)	1	51.65***	3.55 ns	1.95 ns	21.14***	18.70***	124.02***	85.96***	0.13 ns	18.88***	1.30 ns	12.95**
(T) × (F–W)	1	0.02 ns	0.01 ns	8.26**	0.07 ns	3.06*	4.71*	0.24 ns	21.48***	0.03 ns	0.35 ns	8.98*

ns = non-significant.
^a Respiration rate.
^b Electrolyte leakage.
* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.

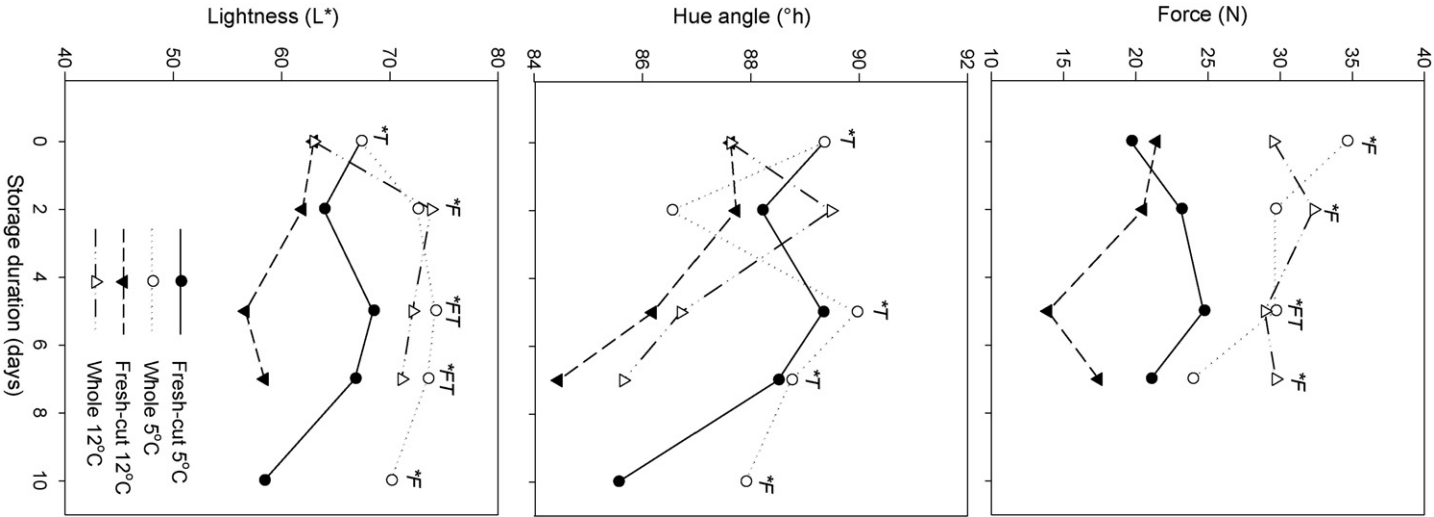


Fig. 3. Changes in firmness, hue angle and lightness during storage of fresh-cut ‘Kent’ mango slices and whole mangoes stored at 5 and 12 °C for Harvest 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 and 12 °C), or both, respectively, using the LSD test.

shown). Moreover, darkening was more pronounced in the fresh-cut slices stored at 12 °C than those stored at 5 °C. Hue angle decreased during storage, but no differences between fresh-cut slices and whole fruit were observed (Table 2). The slices and whole fruit stored at 12 °C had lower hue angle (more orange) than the slices and whole fruit stored at 5 °C (more yellow), probably due to the continuation of ripening during storage at the higher temperature.

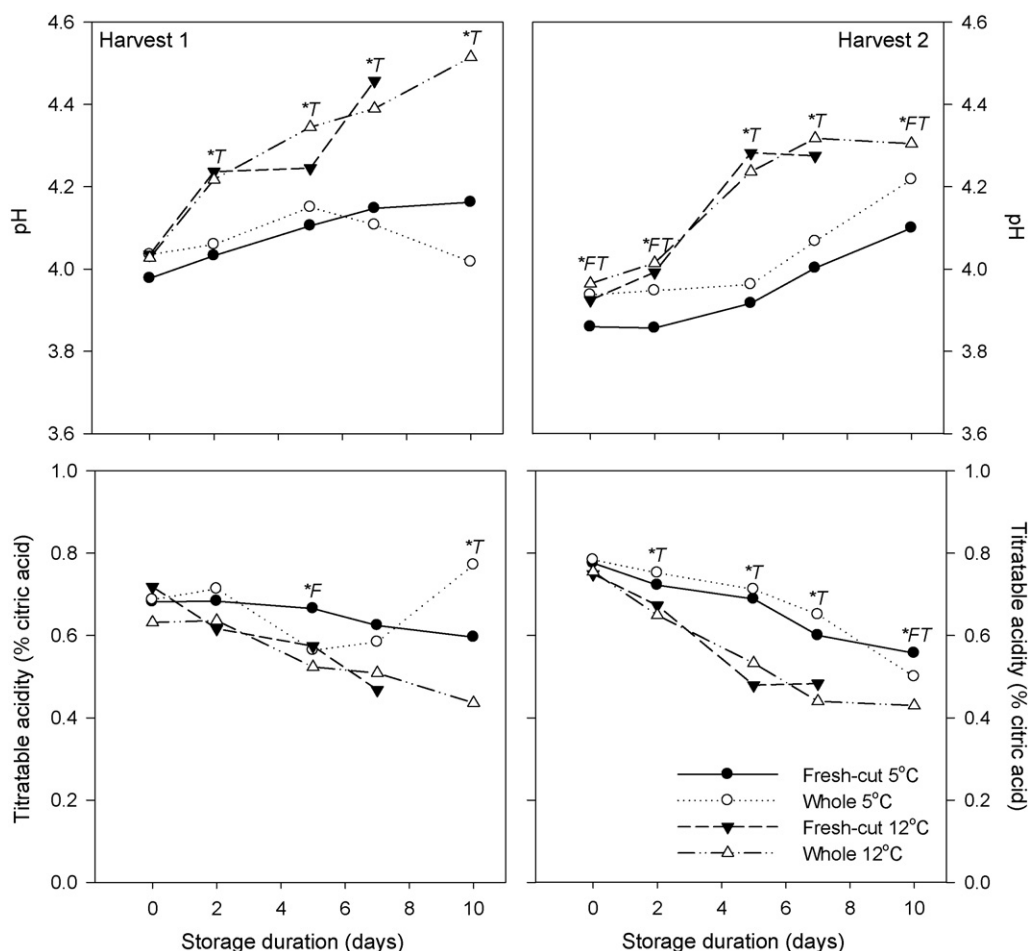


Fig. 4. Changes in pH and titratable acidity during storage of fresh-cut 'Kent' mango slices and whole mangoes stored at 5 and 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha = 0.05$ at that storage time, between fresh-cut and whole fruit, storage temperature (5 and 12 °C), or both, respectively, using the LSD test.

3.6. Fruit composition

3.6.1. pH, titratable acidity, soluble solids content

Storage duration and temperature had a significant effect on the pH of whole and fresh-cut fruit (Table 2). Fruit pH increased significantly throughout storage for all treatments and in both harvests (Fig. 4). Greater increases were observed for the fruit stored at 12 °C than for those stored at 5 °C, but the pH levels were similar for fresh-cut slices and whole fruit. Although there was a statistically significant effect of storage duration on pH, the pH changes were so small (≤ 0.2 pH units) that it would have been practically impossible to detect such differences between fruit by taste evaluations. Several previous studies reported that there were no significant changes in pH during the storage of fresh-cut mangoes (Paull and Chen, 2000; Gil et al., 2006; González-Aguilar et al., 2008).

No significant differences in fruit titratable acidity (TA) were observed, for both harvests, between fresh-cut slices and whole fruit, whereas storage duration and temperature both significantly affected fruit acidity (Table 2). The acidity of fresh-cut and whole mango decreased slightly during storage (Fig. 4). Lower TA was measured in slices and whole fruit stored at 12 °C than in those stored at 5 °C, most likely due to the faster continuation of ripening of the fruit stored at 12 °C. Results from this study agree with others that reported a decline in TA as mangoes ripen (Tharanathan et al., 2006; Karla and Tandon, 1983; Medlicott and Thompson, 1985; Selvaraj, 1989).

Storage duration did not have a significant effect on the SSC of the fruit from both harvests (Table 2). The whole fruit retained significantly higher SSC during storage than the fresh-cut slices, regardless of the storage temperature (Fig. 5). These results are in accordance with some previous reports in which no significant changes were noticed in SSC during the storage of fresh-cut mangoes held at 4 or 5 °C for a period of 8–14 d (Rattanapanone et al., 2001; Gil et al., 2006; González-Aguilar et al., 2008). Lower acidity, higher pH, and higher SSC in whole fruit and fresh-cut slices stored at 12 °C compared to the fruit and slices stored at 5 °C indicates that ripening continued at a faster rate in fruit stored at higher temperature.

3.6.2. Total ascorbic acid

The initial amounts of total ascorbic acid (AA) expressed on a fresh weight basis were much higher in fruit from H1 than in fruit from H2 (Fig. 5). This could be explained by the different growing locations, seasons and climatic conditions under which the mangoes were grown (Lee and Kader, 2000).

For H1, there were no significant effects of storage duration and type of fruit (whole or fresh-cut) on the AA content (Table 2). However, the AA concentration did vary between storage temperatures. On day 2, the whole fruit and slices stored at 5 °C had higher AA than those stored at 12 °C, but for the rest of the storage period, the whole fruit and slices stored at 12 °C had higher AA than those stored at 5 °C (Fig. 5).

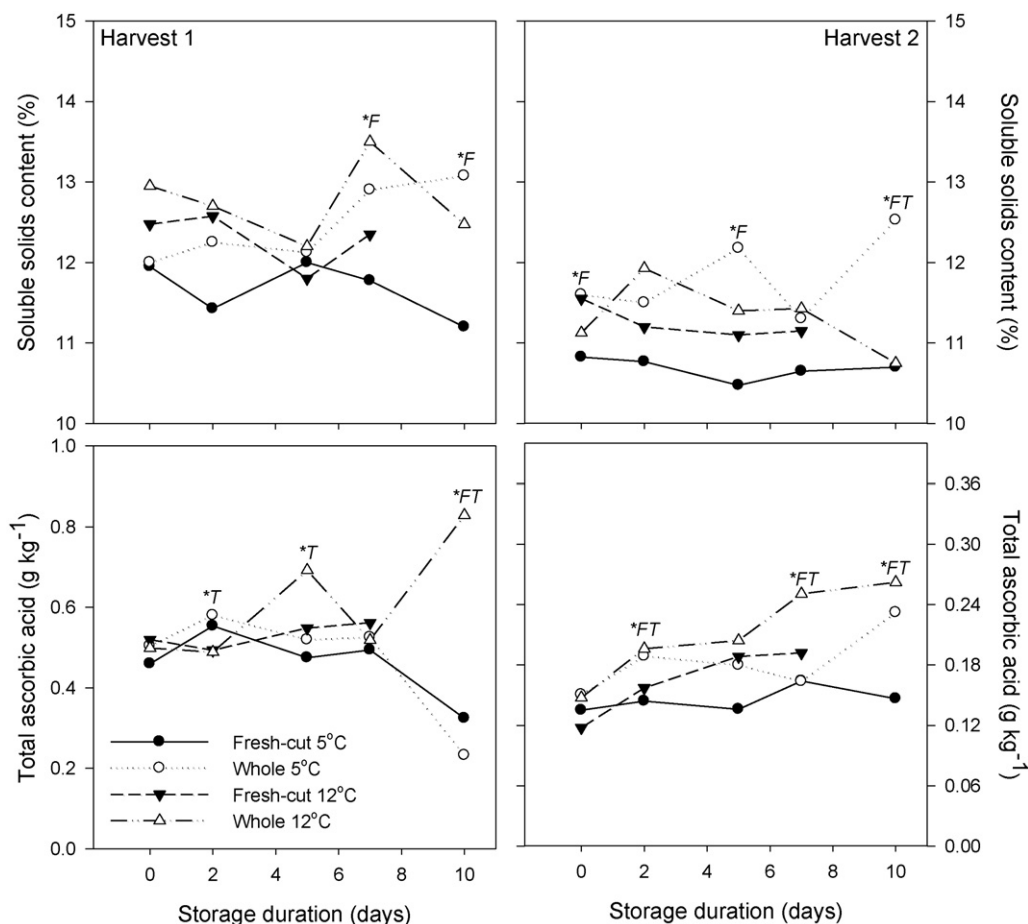


Fig. 5. Changes in soluble solids content and total ascorbic acid during storage of fresh-cut 'Kent' mango slices and whole mangoes stored at 5 and 12 °C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha=0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 and 12 °C), or both, respectively, using the LSD test.

For H2, significant effects of storage duration and fresh-cut versus whole fruit on the AA content were observed (Table 2). The concentration of AA increased during storage and whole fruit showed significantly higher AA than the fresh-cut slices (Fig. 5). There was also a significant effect of temperature on the AA content, with the fruit stored at 12 °C having higher AA than those stored at 5 °C.

It has been reported that in some fresh-cut fruit AA degrades very little during short-term refrigerated storage (about 1 week at 5 °C) (Beaulieu and Gorny, 2004). Tovar et al. (2001) reported that the AA concentration in mango decreased as ripening progressed while the opposite occurred in fresh-cut slices. In fact, they found that the AA content of the slices stored at 5 or 13 °C increased, but never reached the levels measured in the whole fruit. Others have reported increases in AA during refrigerated storage (5, 7, 10 or 15 °C) of 'Alphonso' mangoes and suggested that ascorbate synthesis occurred under such conditions (Thomas, 1975; Thomas and Joshi, 1988). The hypothesis that the increase of AA concentration on a fresh weight basis during storage may be due to water loss during storage rather than to actual increase in AA (Nunes et al., 1998) is not supported in this case since the percentage of weight loss (data not shown) was less than 0.5% of the initial weight and no exudates were noticed in the containers of fresh-cut fruit.

No difference between AA content of whole fruit and fresh-cut slices was observed for H1, while for H2, AA content of fresh-cut slices was lower than in the whole fruit. It is known that levels of AA can decrease after processing or during ripening. Since oxidative processes occur more rapidly in fresh-cut products, these are

expected to have more AA losses compared with whole fruit (Allong et al., 2000). Moreover, the lower AA content of fresh-cut fruit stored at 5 °C compared with those stored at 12 °C, probably due to reactions with reactive oxygen species induced by chilling stress (Tatsumi et al., 2006), suggests that the fresh-cut slices did suffer from CI.

3.6.3. Volatiles

For ease of comparison, and due to the lack of significant difference between the storage temperatures and the fresh-cut versus whole fruit for the majority of the 16 volatiles measured, aldehydes (acetaldehyde, hexanal), ketone (acetone), terpenes (α -pinene, β -pinene, limonene, p -cymene, α -copaene, 3-carene, myrcene, terpinolene, caryophyllene), and esters (ethyl acetate, ethyl butyrate) were summed and presented as total (non-alcohol) volatiles; ethanol and methanol were summed separately and presented as total alcohols (Fig. 6).

Total non-alcohol volatiles decreased during storage for H1 (Fig. 6) but no significant differences were found between whole fruit and fresh-cut slices or between storage temperatures (Table 2). Changes in total alcohol content were also observed during storage (Table 2), with the least alcohol content measured on day 10 (Fig. 6). No difference between fresh-cut slices and whole fruit or between storage temperatures was observed (Table 2). In fact, acetaldehyde, methanol, myrcene, and ethylacetate were the only volatiles to show significant changes during storage (data not shown). In general, acetaldehyde concentration decreased by day 5 and remained constant for the rest of the storage, while methanol was signifi-

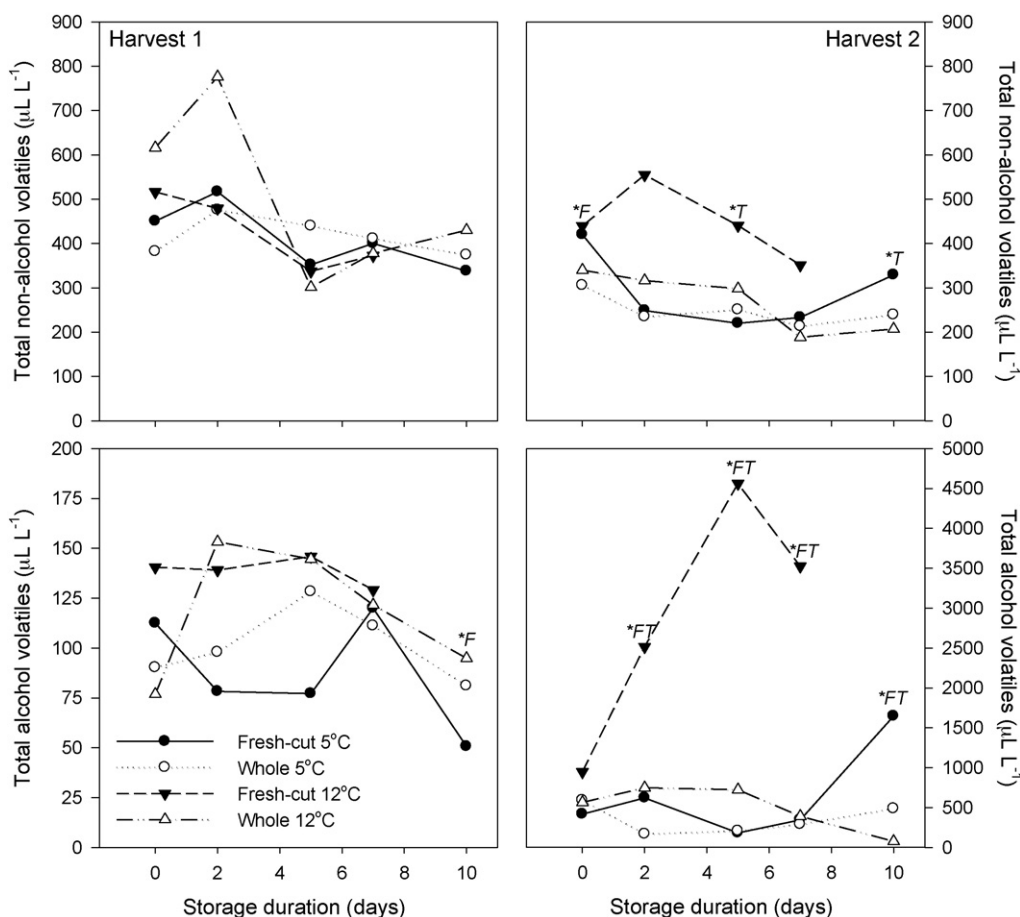


Fig. 6. Changes in total volatiles (aldehydes, ketones, terpenes and esters) and total alcohols (methanol and ethanol) during storage of fresh-cut 'Kent' mango slices and whole mangoes stored at 5 and 12°C for Harvests 1 and 2. The symbols *F, *T or *FT indicate a significant difference at $\alpha=0.05$ at that storage time between fresh-cut and whole fruit, storage temperature (5 and 12°C), or both, respectively, using the LSD test.

cantly higher on day 2 and higher concentrations of myrcene and ethyl acetate were present on day 10.

For H2, however, there was significantly higher content of alcohols (mainly ethanol) throughout the storage period in the fresh-cut slices stored at 12°C, and on day 10 for the fresh-cut slices stored at 5°C compared with the whole fruit. No significant differences were found for the total non-alcohol volatiles present in the fruit from H2. But, when the volatiles were analyzed individually, acetaldehyde, ethyl acetate, and ethyl butyrate were significantly reduced in fruit stored at 5°C compared with 12°C (data not shown). However, acetaldehyde content was higher in stored fresh-cut slices compared to whole fruit at 5°C, while whole fruit had higher α -pinene, limonene, and *p*-cymene contents. At 12°C, fresh-cut slices had higher content of acetaldehyde, acetone, ethyl acetate, and ethyl butyrate compared with whole fruit (data not shown).

It is known that anaerobic respiration in fruit tissues is characterized by increases in ethanol, ethyl acetate, ethyl butanoate, and acetaldehyde (Beaulieu and Lea, 2003). The major plant fermentative metabolic products in fruit are ethanol and acetaldehyde and their accumulation is well-correlated with off-flavor development (Ke et al., 1991; Ke and Kader, 1992; Agar et al., 1999). Normally these volatiles accumulate at low levels during mango fruit ripening and thereby play an important role in the development of mango aroma volatiles. But, following exposure to anoxic conditions, acetaldehyde and ethanol may be markedly enhanced, leading to the perception of off-flavor (Shi et al., 2007). For example, Sothornvit and Rodsamran (2008) reported that both storage dura-

tion and temperature significantly affected 'Nam Dokmai' mango flavor, and panelists indicated that off-flavors caused by the release of alcohol and acetaldehyde were the main attributes negatively affecting mango flavor. In this study, development of such off-flavor was observed only in the fresh-cut slices stored at 12°C.

It is also known that chilling temperatures adversely affect volatiles production. Nair et al. (2004) reported that the mean total monoterpenes, sesquiterpenes, hydrocarbons, esters, aldehydes, norisoprenoids, and total aroma volatiles were significantly reduced in whole 'Kensington Pride' mangoes stored at chilling temperature (5°C) compared to the fruit stored at non-chilling temperature (15°C).

Overall, in this study, volatile profiles did not appear to be greatly compromised by exposure to chilling temperature, although subjective evaluation indicated that aroma intensity tended to decline more during storage of fresh-cut slices at 5°C than at 12°C.

This difference in aroma perception during subjective evaluation could be explained by a modest decrease in one or more odor active volatiles due to low storage temperature that was not confirmed by statistical analysis. Also, volatiles not measured during this study, such as lactones, which are believed to be important flavor notes in some Indian and Florida varieties (Wilson et al., 1990), or others such as sesquiterpenes or ketones (Pandit et al., 2009), could have been affected by low storage temperature (Nair et al., 2004) and modified the aroma of fresh-cut slices. It is also possible that, at the time of sensory analysis, the samples were not all at the same temperature, which could have affected the aroma

perception. In fact, all samples from 5 °C were exposed to room temperature (22 °C) for less than 1 h before being evaluated, while those from 12 °C were evaluated upon removal from the storage room. Thus, there may have been less aroma volatilization and lesser aroma perceived in the colder samples. It is also probable that, compared to the slices stored at 12 °C, which rapidly developed a strong off-flavor during storage, the 5 °C samples would be perceived to have less strong aroma in comparison.

4. Conclusion

This study compared the effect of chilling (5 °C) and non-chilling (12 °C) storage temperatures on the quality and physiology of fresh-cut 'Kent' mango slices and whole mango fruit controls. The most striking difference between the two storage temperatures was the appearance and aroma of the slices and to a lesser extent their compositional changes. While the shelf-life of fresh-cut mango slices based on visual appearance was about 5–6 d at 5 °C versus 3–4 d at 12 °C, the mango aroma intensity declined more in slices stored at 5 °C. It is unclear whether the storage duration at 5 °C was sufficiently long to cause CI in the fresh-cut mango slices since no visual CI symptoms developed in the whole fruit, however, reduced AA content, higher titratable acidity, reduction of volatiles, and increased softening of whole fruit stored at 5 °C, which are all indicative of CI, suggest that the fresh-cut slices probably experienced chilling stress.

Nevertheless, the putative injury of fresh-cut 'Kent' mango slices resulting from exposure to 5 °C was less significant than the more rapid visual and textural deterioration and off-odor development of the fresh-cut slices stored at 12 °C. Thus, fresh-cut mango slices had longer shelf-life when stored at 5 °C than at 12 °C despite the possibility of CI, because the negative appearance and aroma changes that occurred at the higher temperature were more objectionable than the relatively minor negative changes that occurred at the lower temperature. Thus, development of methods to minimize negative quality changes occurring in fresh-cut mango slices are required in order to improve product shelf-life at both chilling and non-chilling temperatures.

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